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Self-Charging System for Electric Vehicles

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Abstract
In this research paper is a study of a technique that is used in the charging of electric vehicles. This technique, which is registered as a patent, is represented by adding electric generators to supply the electric vehicle with a portion of the energy which is needed for it. This technique has been studied in this research paper and a number of important things have to be considered when dealing with this topic, the most important things that have been studied are the effects on the speed of the electric vehicle, the regenerative braking and the amount of energy that can be provided through this innovation. This research paper includes design of DC-DC Boost converter with two loops PID controllers and design for a Field Oriented Control (FOC) of electric AC motors.

Keywords: Electric vehicles self-charging system, Boost converter with double loops controller, vector control of electric AC motors.
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1. Introduction

Electric Vehicles EVs are considered the most promising technology in the world because of their positive impact in reducing negative impacts on the environment and the developments in this technology that make them compete with traditional fuel-powered vehicles. However, Electric Vehicles still have many issues which need to be solved, this issues related to battery of the vehicle. The capacity of the battery makes represent a challenge for the driving limit, and it increase the EVs costs and the battery takes longtime of recharging in some cases (Schaltz, 2011). Because of that matter, many patents attempt to explain solutions to these problems, one of these patents is the self-charging electric cars (Al-otaibi, 2020), The inventor invented a method to add power generators to the EVs so that these generators are able to cover part of the electric energy that the battery needs during a single trip. This method is representing by adding a gear ring to the wheels in EVs. A transmission and a gearbox will transfer the motion from the wheels to the auxiliary generators as shown in figure 1. The aim of the study is to provide the EVs of apportion of energy that the vehicle consumes in a single trip, which means that the EVs can travel for a long distance.

Electric vehicles used a high-voltage battery has a voltage greater than 200 volts. The battery has many types as lithium ion battery which is the type that is used in the study. The induction motors, permanent magnetic synchronous motors and switch reluctance motors are the main types of electric motors in electric vehicles. The power electronics will drive the motor (AC motor drive) and the regenerative braking will be when the motor work as a generator. The induction motor which is easy to control it using the field oriented control (FOC) method, switched reluctance motor has a simple structure, low cost, low efficiency and small size in comparison with other motors. The permanent magnetic synchronous motor can work with a wide range of speed without gearbox and it has high efficiency and high torque at low speed and it can be used at in-wheel motor system (Un-Noor *et al.*, 2017).

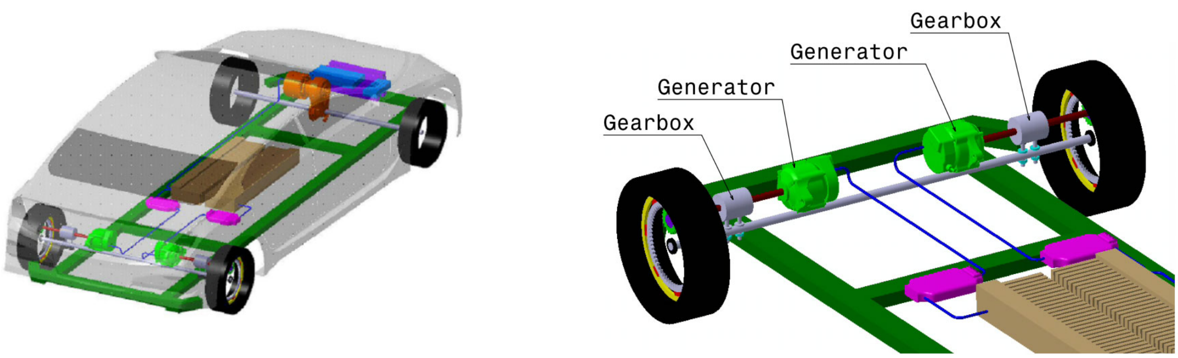

Figure 1: Electric Car with Self charging System.

2. Dynamic and Force Model

Study the vehicle dynamics is very important to obtain the different responses of an electric vehicle when it is driven on the road. This topic includes a study of the air effects on the vehicle, Rolling Resistance Force, vehicle

mass, vehicle speed, car's frontal area, and other factors (Terras *et al.*, 2011).
The Forces at the Plane

$$F_f = \frac{T}{L} G_r \tag{1}$$

F_f	*Resultant force*
T	Torque Produce by the Motor
L	Distance from center of rotation
G_r	Gear ratio

Aerodynamic Drag

$$D = \frac{1}{2} \rho v^2 S C_D \tag{2}$$

D	Drag Force
ρ	The air Density
v	The Car Velocity
S	Car's frontal area
C_D	Coefficient of the drag

Rolling Resistance

$$F_r = C_r m_T g \tag{3}$$

F_r	Rolling Resistance Force
C_r	The Rolling resistance coefficient
m_T	The total mass of the car
g	The gravitational constant

The gravitational force

$$F_{gx} = Mg\, sin(\beta) \tag{4}$$

F_{gx}	The gravitational force
M	The total mass of the vehicle
β	The grade angle with respect to the horizon

3. DC- DC Boost Converter

In EVs there are two energy storage devices, the first one is the main energy system (MES) which has a high energy storage capability and the second one is the rechargeable energy storage system (RESS) which is a high power capability (Al, Van and Gualous, 2011).

Direct current – Direct current (DC-DC) converter boost type is used in many applications as renewable energy and electrical vehicles. The transfer function of DC-DC Boost converter represents the relation between the inductor current and the duty cycle is written by equation (5), and the transfer function in equation (6) represents the relation between inductor current and output voltage (V, 2019). By comparing the Boost Converter with the Buck and Buck-Boost Converter; the Boost Converter is harder than the other types because it has a zero root in the right half of the s-plane and it is considered as a non-minimum phase system (Abdel-Gawad and Sood, 2014). In this section a design for Boost Converter with two loop PI controllers increase the voltage from 200V to 400V as shown in figure 2 and 3. Table 2 shows the standard DC-DC Boost converter parameters (Schaltz, 2011).

$$G_{iLB-d} = \frac{i_{LB}(s)}{d(s)} = \frac{RC_{dc}V_{dc}s + [(1-D)RI_{LB} + V_{dc}]}{RC_{dc}L_B s^2 + L_B s + R\,(1-D)^2} \tag{5}$$

$$G_{vdc-iLB} = \frac{v_{dc}\,(s)}{i_{LB}(s)} = \frac{-I_{LB}RL_B s + V_{dc}R(1-D)}{V_{dc}RC_{dc}s + [V_{dc} + (1-D)I_{LB}R]} \tag{6}$$

The parameters of inductor and capacitor can be calculated by equations (7) and (8)

$$L = \frac{V_{out}}{4 \times F \times \Delta I_{L\,max}} \tag{7}$$

$$C = \frac{I_{L\,max}}{4 \times F \times \Delta V_{out\,max}} \tag{8}$$

$\Delta V_{out\,max}$	Output voltage ripple (1% of output voltage)
V_{out}	Output voltage (400 V)
V_{in}	Input voltage (200 V)
F	Switching Frequency 20 kHz
$I_{L\,max}$	Maximum current (250 A)
$\Delta I_{L\,max}$	Inductor Current ripple (5% of $\Delta I_{L\,max} = 12.5\ A$)

Table 1: The parameters of Boost Converter.

Controller Parameters

- ❖ Current Controller (PI)

$$K_{p\_I} = 18$$
$$K_{i\_I} = 22$$

- ❖ Voltage Controller (PI)

$$K_{p\_V} = 1.5$$
$$K_{i\_V} = 2$$

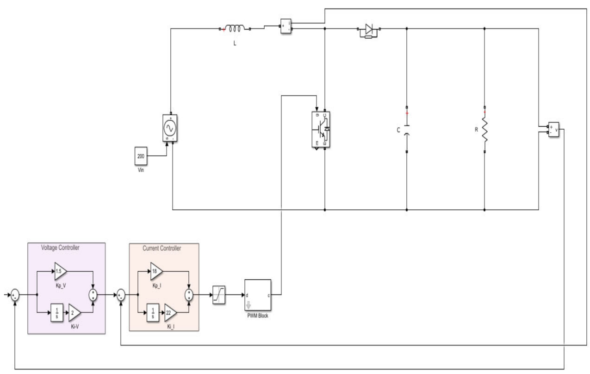
Figure (2): DC/DC Boost Converter with two controller

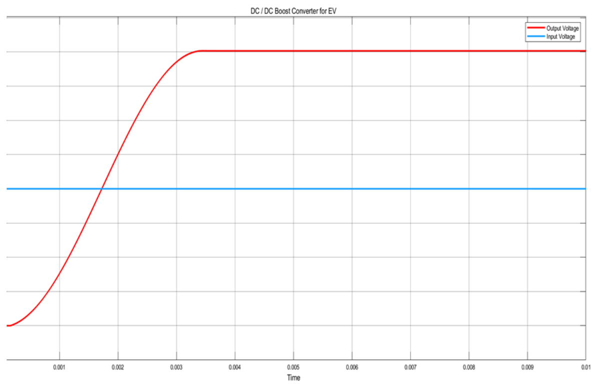

Figure (3): The output of DC/DC Boost Converter for Electric Vehicles.

4. Field Oriented Control of AC Electric Motor

The Field Oriented Control (FOC) is widely used in the control of AC motors in Electric Vehicles, FOC uses the pulse width modulation (PWM) and linear controllers to control the components of load voltages (Wang *et al.*, 2018).

There are many advantages of Field Oriented Control (Gopal B T, 2017) as improve the torque response, allow controlling the torque at low speed and frequency, Dynamic speed accuracy, short-term overload capability, reduce the motor size, cost and power consumption and the motor can work in the four quadrants. The FOC is controlling the stator currents represented by vectors. This type of control lead to a structure similar to DC machine control by transforming the three phase time and speed dependent into a two coordinates d and q frame time invariant system (Schaltz, 2011).

- Model of an Induction Motor

  The induction motor can be modeling by the following equations (Wang *et al.*, 2018).

$$v_s = R_s . i_s + \frac{d}{dt}\varphi_s \tag{9}$$

$$0 = R_r . i_r + \frac{d}{dt}\varphi_r - j.\omega.\varphi_r \tag{10}$$

$$\varphi_s = L_s . i_s + L_m . i_r \tag{11}$$

$$\varphi_r = L_r . i_r + L_m . i_s \tag{12}$$

$$T = \frac{3}{2}.p.Im\{\varphi_s^* i_s\} \tag{13}$$

Where v_s is the stator voltage, φ_s and φ_r are the stator flux and the rotor flux, i_s and i_r are the stator current and the rotor current, R_s and R_r are the stator and rotor resistances. L_s, L_r and L_m are the stator, rotor and mutual inductance, ω is the electrical speed, p is the number of pole pairs and T is the electromagnetic torque.

- ❖ I_d Current Controller (PI)

$$K_{p\_Id} = 102$$
$$K_{i\_Id} = 5$$

- I_q Current Controller (PI)

$$K_{p\_Iq} = 95$$
$$K_{i\_Iq} = 6$$

- Speed Controller (PI)

$$K_p = 0.9$$
$$K_i = 0.42$$

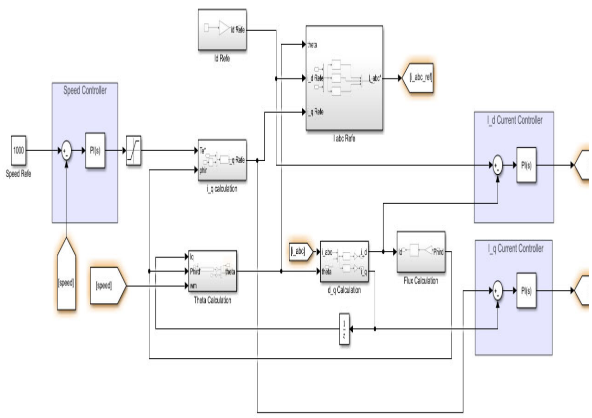

Figure (4): FOC Control Block.

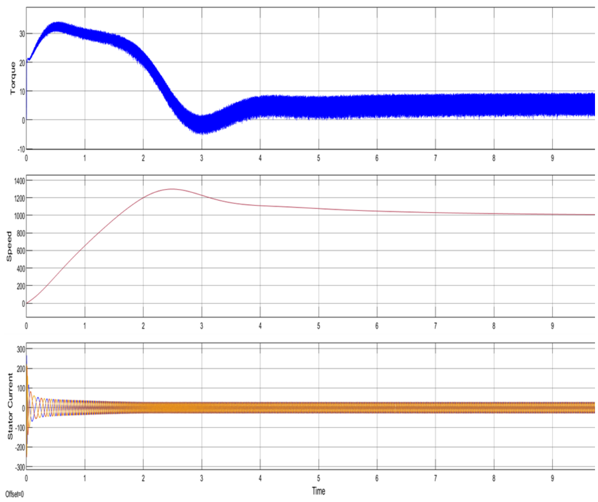

Figure (5): FOC for Induction Motor 50HP 37 Kw with reference Speed = 1000 rpm.

5. Case study

This paper studied a special design was made by the researcher and was registered as patent (Al-otaibi, 2020). In this paper, the system was studied by MATLAB and measuring the effects of adding one and two auxiliary synchronous generators to the vehicle as mentioned previously on the performance of the electric vehicle. The electric vehicle uses the Permanent magnet synchronous motor (PMSM) and a 3 kW generator was used and connected to the wheels through a gearbox with a 1:4 conversion ratio.

The effect of the invention on the speed of the vehicle was studied when adding a generator and when adding two generators. Also, the effect of the invention on the energy consumed from the battery and the effect of adding generators on regenerative generation were explained through the proposed path during the trip.

From the study, adding the generators will make the electric car to slow down and speed of it will decrease, as shown in the figure 6, This result was expected to happen because adding the generators to provide a portion of the energy that is consumed by the electric vehicle means that there is a portion of the electric motor's power will go to provide torque for the generators.

The figure 7 shows the energy consumed by the battery during one trip that the electric car takes and the study demonstrated a decrease in the energy consumed during the trip when adding the generators. However, on the other hand, the study showed that the regenerative braking decreased and its decreasing was greater when two generators were added compared to adding one generator and the invention can save more than 20% of the energy consumed within the conditions that have been studied for both the design of the car in table 2 and the drive cycle, knowing that the amount of energy which is saved changes depending on the shape of the road and movement path. And what we recommend is to use only one generator because using two generators will greatly affect the regenerative braking and thus when comparing energy savings with costs and negative effects on speed, using one generator is better than using two generators as shown in figure 7. In figure 8 the losses in battery decreased when the generators were added to the vehicle, and figure 9 shows the total charging amount of battery from the auxiliary generators and regenerative braking. In figure 10 the power of generators during the period of trip ant it depends on the speed vehicle.

Mass	1400 Kg
Number of wheels per axle	2
Horizontal distance from CG to front axle	1.45 m
Horizontal distance from CG to rear axle	1.65 m
CG height above ground	0.5 m
Gravitational acceleration	9.81 m
Frontal area	2.26 m^2
Drag coefficient	0.42
Air density	1.18 kg/m^3

Table 2: The parameters of electric vehicle.

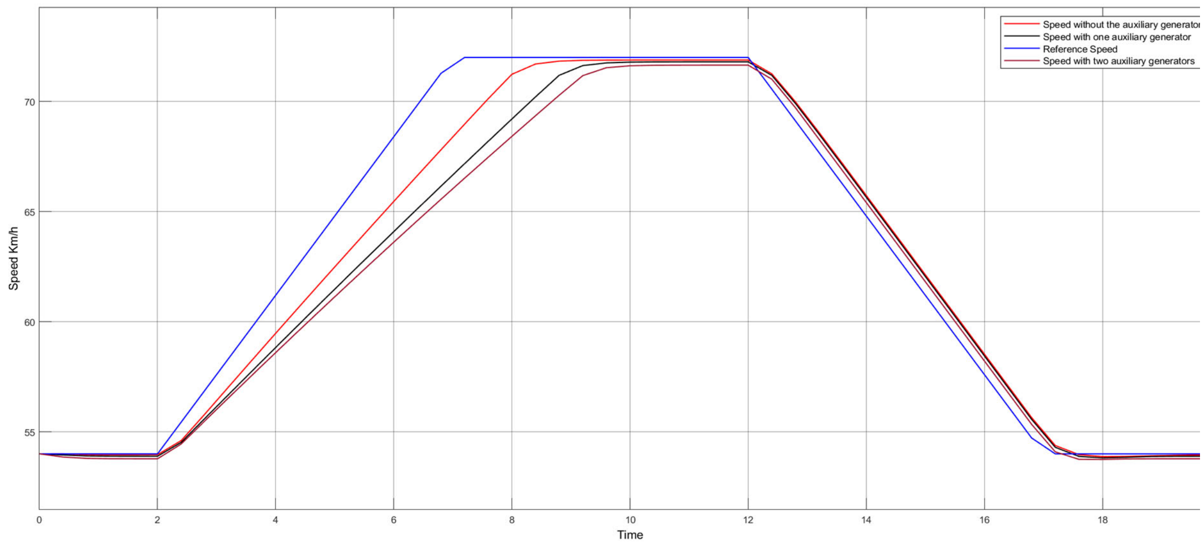

Figure 6: The speed of the electric vehicle.

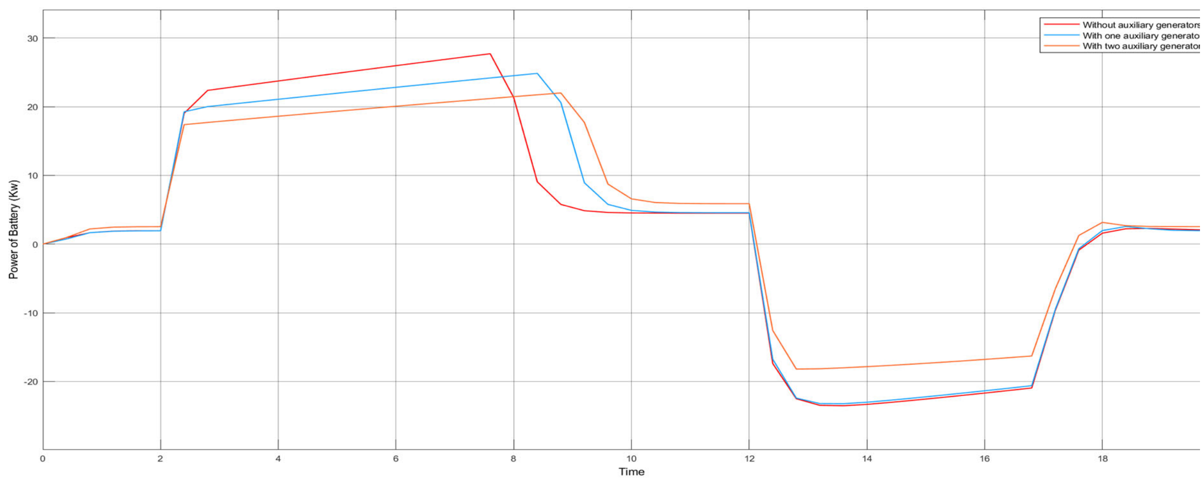

Figure 7: The energy which is consumed by the battery.

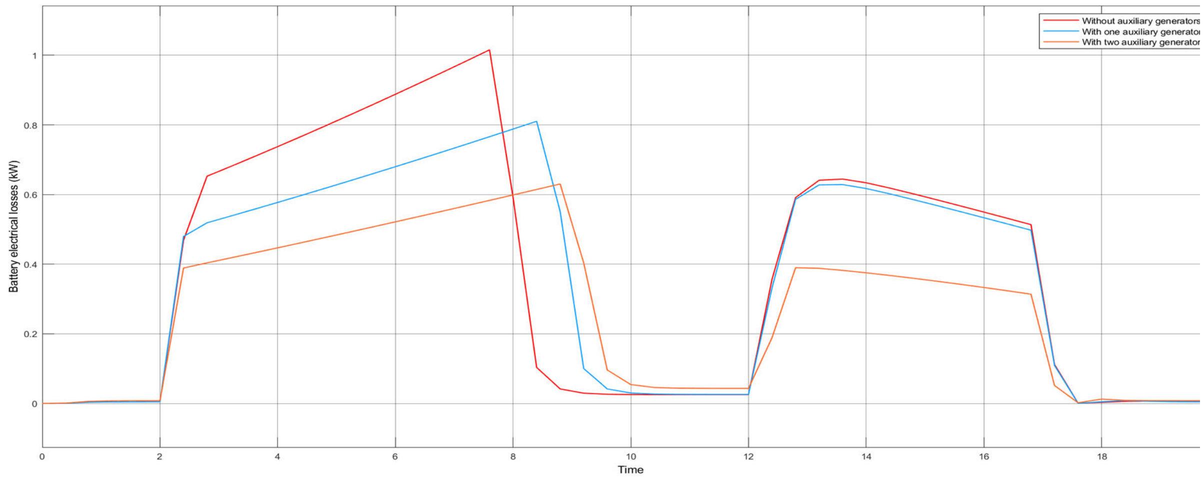

Figure 8: The losses in battery.

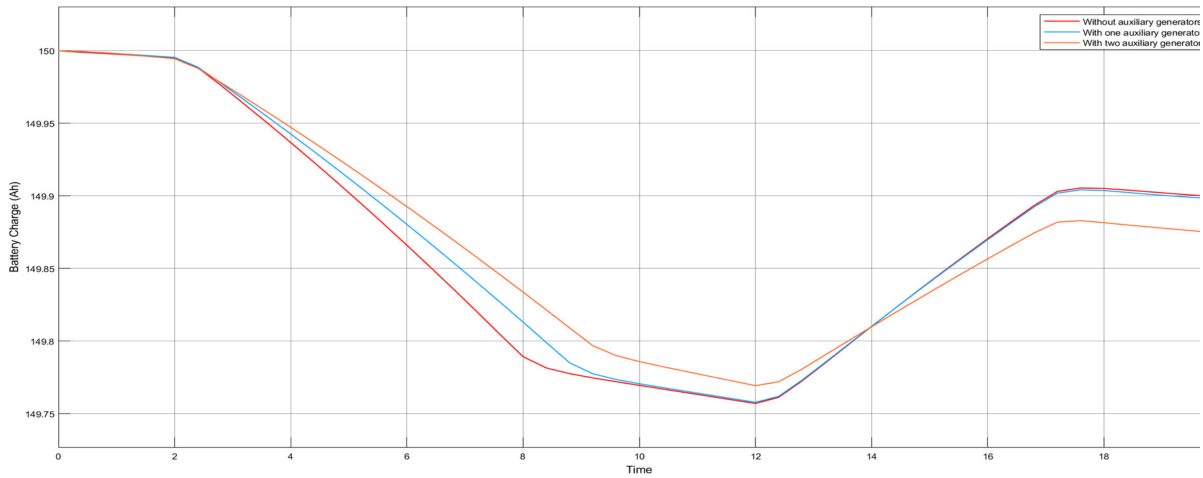

Figure 9: Battery recharging.

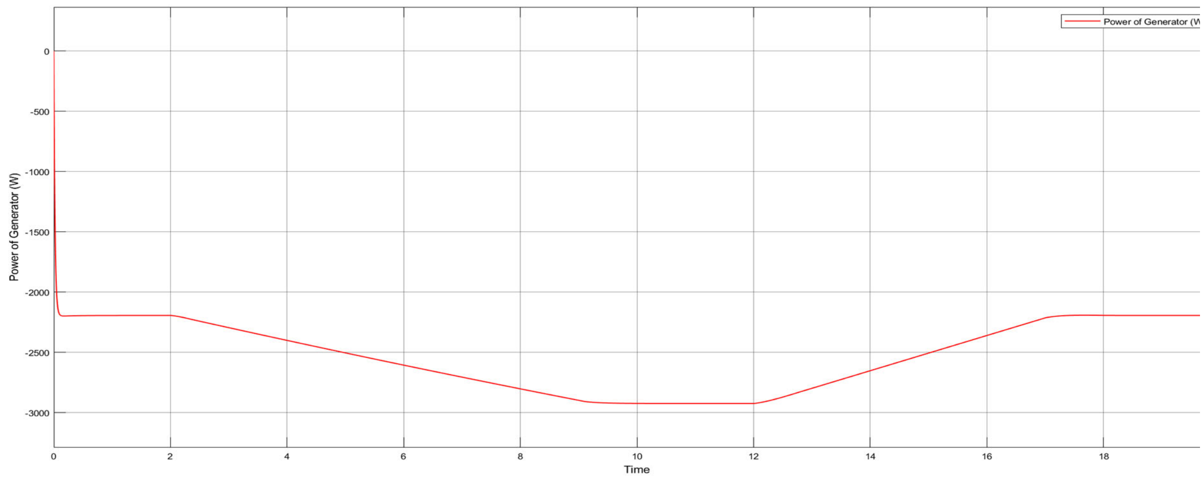

Figure 10: The power of generator.

6. Conclusion

This paper discussed a method for charging electric vehicles during its trip, and the aim of this paper is to know the amount of electrical energy that can be supplied to an electric vehicle by installing this system and adding it to electric vehicles.

The paper takes into care the speed of the electric car, the energy which is consumed by the battery, the losses in battery, Battery recharging, and the power of generators.

The study found that 20% of the energy which is needed for an electric vehicle can be saved during the trip if we are using one generator as shown in figure 11, but this amount decreases when using two generators, and the reason for this the using of two generators will lead to decreasing in the speed of the electric vehicle, which leads to a reducing in the amount of energy we obtain from the regenerative braking.

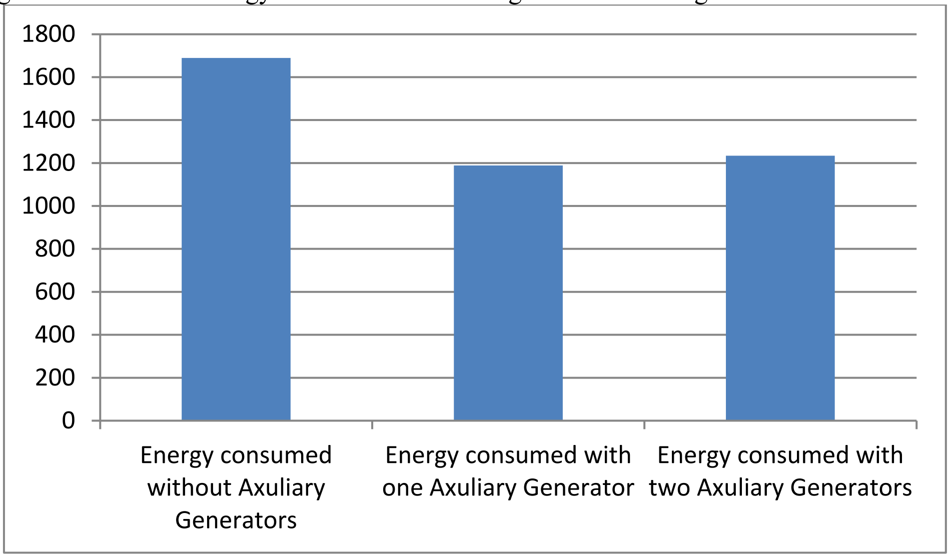

Figure 11: The amount of energy that is needed to electric vehicle during one trip.

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